(NASA-TM-X-68262) H2-O2 AUXILIARY POWER UNIT FOR SPACE SHUTTLE VEHICLES Progress Report (NASA) ~~8~~ 9 p HC $3.00 CSCL 10C
N73-29005
Unclas
G3/03 11462

NASA TECHNICAL MEMORANDUM

NASA TM X- 68262

NASA TM X- 68262

H_2-O_2 AUXILIARY POWER UNIT FOR SPACE SHUTTLE VEHICLES--A PROGRESS REPORT

by Joseph P. Joyce, Donald G. Beremand,
Harry M. Cameron, and Kent S. Jefferies
Lewis Research Center
Cleveland, Ohio 44135

TECHNICAL PAPER proposed for presentation at
Eighth Intersociety Energy Conversion Engineering Conference
Philadelphia, Pennsylvania, August 13-17, 1973

H_2-O_2 AUXILIARY POWER UNIT FOR SPACE SHUTTLE VEHICLES--A PROGRESS REPORT

*Joseph P. Joyce, Donald G. Beremand, Harry M. Cameron, & Kent S. Jefferies
National Aeronautics & Space Administration
Lewis Research Center
Cleveland, Ohio

E-7553

Abstract

The Lewis Research Center is conducting a program to establish technology readiness of hydrogen-oxygen (H_2-O_2) auxiliary power units for use on board the space shuttle orbiter vehicle. The primary effort in this program is a thirty-one month contract being conducted at AiResearch Manufacturing Co. (NAS3-15708). Fundamental objectives include experimentally establishing an acceptable propellant flow control method, verification of combustor stability, and adequate thermal management. An initial APU configuration with recycled hydrogen flow has been studied and revised towards greater simplicity and scaling ease. The selected APU is a recuperated open-cycle, turbine-driven unit. Series flow of cryogenic hydrogen removes internally-generated heat and heat from the hydraulic system. Steady-state test of the combustor has been successful. All other APU components are either being fabricated or are in the final stages of detail design. Ultimately an APU will be assembled as a close-coupled unit for performance and endurance testing. This paper states the H_2-O_2 APU program progress. The revised configuration schematic and its calculated performance are reviewed. A weight comparison is made between the shuttle baseline hydrazine and H_2-O_2 APU systems, showing that hydrogen-oxygen APU's have the potential of increasing the payload of the space shuttle.

Purpose

The APU provides hydraulic and electrical power on board the shuttle orbiter during launch to orbit and reentry through landing phases of operation. Peak short-duration power is demanded for thrust vector control, aerodynamic control surface movement and eventual landing gear deployment and braking on the ground.

The H_2-O_2 APU specifications (Table 1) are highlighted by a power turndown ratio equal to 16 and a wide range of inlet temperature conditions for the H_2 and O_2. The APU must respond to full range (idle-to-peak) power changes in 0.075 seconds while holding speed within a ± 5 percent tolerance band and without incurring detrimental turbine inlet temperature changes. Hydrogen cools the APU lubricant and hydraulic pump case drain flow. APU durability is characterized by 1000-hours life at design temperature and multiple start capability with H_2 and O_2 and with cold inert gas for system checkout on the ground. The 1000-hours life was selected early in the shuttle program to include 100 flight cycles with up to three hours operation during each cycle, plus allowance for APU checkout and use of the APU for vehicle checkout between flights.

Shuttle APU power profiles have changed considerably over the years since the program began. The latest profile (fig. 1) has a duration of about 1.5 hours. The peak power of 147 HP is considerably less than the 400 HP peak selected for the H_2-O_2 APU technology program. When selected, 400 HP represented a median peak level for the contemporary vehicle designs. Since our objective was to demonstrate technology readiness, we chose to avoid the many program perturbations and retained the 400 HP level and 1000-hours life. The character of the profile is the same now as it was in the beginning--namely, most operation at low power with a few high-power spikes.

Description

The schematic of the initially selected reference APU system was described in IECEC paper 729069.[1] It incorporated jet pumped recycled hydrogen flow to prevent hydrogen below 400°R from reaching the lubricant and hydraulic coolers. Calculations showed that the jet pump would span the required turndown ratio only with great difficulty. Also, the primary ejector flow had to pay a high-pressure drop, about 130 psid at maximum power to pump the primary plus recycle flows through the heat exchangers and recycle valve.

A better solution was sought and found. The revised configuration (fig. 2) eliminates the jet pump and flow recirculation, and adds a hydrogen regenerator. Hydrogen heated by turbine exhaust products provides an initial hydrogen preheat. Hydrogen, which has cooled the hydraulic oil, is again cooled to 400°R in the hydrogen regenerator while further heating the supply hydrogen to at least 400°R. Hence, the effective hydrogen cooling capability is doubled.

Because the jet pump and its primary hydrogen flow pressure drop were eliminated, it was possible to (1) reduce the required hydrogen supply pressure from 675 psia to 575 psia and (2) to increase the hydrogen flow control valve pressure drop at peak power from 60 psid to 100 psid. The hydrogen control valve design margin and the probability of combustor stability were thereby increased.

*Aerospace Engineer, Member AIAA.

Propellant flow to the combustor is controlled by separately actuated, electronically linked valves. By virtue of the recuperator bypass valve and the hydrogen-oxygen temperature equalizer, both propellants reach their flow control valves at equal temperatures up to a peak of 750°R at low power. Feedback of turbine rotational speed actuates both valves to change the total flow rate and maintain design speed ± 1 percent at steady state and ± 5 percent during load changes. Feedback of turbine gas flow temperature trims the oxygen valve flow area to control oxygen/fuel ratio and hold the design temperature level. Oxygen trim is controlled both on rate of temperature change and absolute temperature signal to meet the response requirements. Each valve is a short (0.050") stroke-twin poppet design (fig. 3). Pressure balancing is used to reduce the force required for flow area modulation. Durability is increased because no dynamic seals are used.

Performance

The specific propellant consumption (SPC) for the initial APU design (as presented in IECEC paper 729069) and the revised APU are approximately equal. Their SPC values are shown in Figure 4. The sharp rise in SPC at low power is due to parasitic losses, including a constant gearbox loss assumption of 24 HP. Although the SPC is high, the propellant flow rates are low. As power output increases above 50 to 100 HP, the SPC decreases to a value below 3 LB/HP-HR and swiftly approaches a value of about 2.2 LB/HP-HR. At the 22 percent full-power level representative of the average power for the present shuttle APU power profile, the revised APU has an SPC of about 3.0 LB/HP-HR.

The SPC values are an output of the APU analysis[2] which is complete. The digital computer program generated by AiResearch for APU performance calculation is also operational at the Lewis Research Center. Stable APU operation is predicted throughout the specified range of operating conditions.

The combustor was placed on test early and its steady-state testing has been satisfactorily completed. The turbine-gearbox and H_2-O_2 temperature equalizer are being fabricated. All remaining test hardware are in detail design.

An external as well as a cross-sectional view of the combustor is presented in Figure 5. Hydrogen cools the chamber wall. A spark plug gap of 0.015" with a 5 millijoule/spark discharge successfully ignited the propellants for stable combustion at all test conditions. The test conditions covered and exceeded the required range of flow rates with C* efficiencies calculated to be approximately 100 percent.

The combustor supplies a flow of hydrogen and superheated steam at 1960°R to the turbine shown in Figure 6. It is a two-stage axial flow, partial admission turbine, overhung from a stub shaft supported by two angular contact ball bearings. Heat soakback from the turbine wheels to the bearing lubricant has been minimized by reducing the heat conduction cross-section area in the stub shaft and providing extensive thermal insulation in the static parts. A close clearance hydrodynamic-type face seal[3] is used to reduce heat generation.

The flight turbine design was modified slightly to avoid development problems and to provide a "workhorse" unit that would be trouble free. Thus, the program could concentrate on the fundamental areas of concern--i.e., propellant flow control, combustor stability and thermal management. The resulting component has the fluid dynamics and general arrangement of the flight turbine. However, a labyrinth seal with an inert gas buffer has been substituted for the dynamic face seal. Thus, seal development is avoided. Also, when combustion is stopped, it should be possible to continue flowing oil to the bearings to remove heat soakback from the hot turbine parts which are not as well insulated as in the flight design. The bearing loads and DN value of about 1.6×10^6 RPM-MM result in a combined bearing B_{10} life of about 1000 hours. This life is more than adequate for our technology test program, viz. about 125 hours. However, special design techniques will be required for this general arrangement to achieve a B_1 life of 1000 hours which is considered necessary for flight qualification.

Material Compatibility

Hydrogen environment embrittlement was a primary concern in the selection of structural materials. For example, the austenitic stainless steel V-57 was substituted for the initially selected U-700 nickel base alloy which exhibits loss of strength and ductility when exposed to hydrogen. Austenitic stainless steels, as a class, resist embrittlement when exposed to hydrogen[4]. A limited materials support program is in progress to verify properties of V-57 in hydrogen. Test specimens will be cut from the same material being used to fabricate the turbine rotor.

Another high-strength nickel base alloy, Astroloy, specially processed by Pratt & Whitney did resist hydrogen environment embrittlement[5]. NASA has purchased a quantity of Astroloy for limited tests in hydrogen and possible wheel fabrication. It has the same chemical composition and has received the same heat treatment as the P&W material. If the effects of hydrogen environment are negligible, it would be possible to decrease SPC values by 10 percent via the increased turbine-inlet temperature and rotational speed permitted with Astroloy wheels.

Cooling

A significant potential of the APU lies in the area of fluid cooling (fig. 7). Not only can the lubricant and case drain hydraulic fluid be cooled but, when supplied as a cryogenic fluid at 55°R, hydrogen can theoretically absorb the entire useful and parasitic output of the APU. This higher heat input to the hydrogen permits an increased set point temperature for the propellants at their flow control valves which should result in slightly reduced SPC.

Weight

A shuttle APU system (4 APU's per system) weight comparison is presented in Table 2. The H_2-O_2 APU weights have been sized individually for 50 HP-HR and a peak of 150 HP. The H_2-O_2 APU pumped and supercritical system (tankage + support) weights stated are averages of values calculated by AiResearch and Lewis Research Center. Both H_2-O_2 APU systems (pumped and supercritical hydrogen supply systems) are lighter than the hydrazine pumped system. This is due to the high hydrazine system SPC and its need for a water coolant system to remove lubricant and hydraulic system heat. An increase in required system energy results in greater weight reductions as illustrated in Figure 8. For example, at a system energy level of 320 HP-HR, the H_2-O_2 pumped APU system is estimated to weigh about 2000 lbs. less than the hydrazine system.

Test

Since the major portion of our present contract program at AiResearch involves test, it is well to review the test schedule. Individual components are tested first to verify structural integrity and to measure actual performance. Tests are tailored to the component type and the function it plays in the APU. Later, two subsystems are tested. The turbine and gearbox subsystem is first operated to measure bearing lubricant flow requirements, parasitic torques, and turbine performance with facility heated air. Next, the combustor and controls subsystem is tested with an analog simulator of the turbine. The controls will first be operated "open-loop" with the turbine analog. This subsystem is considered the heart of the APU. Controlled startup sequences, combustor stability with combined valve and injector pressure drops, and control response to perturbations in turbine speed and temperature will be investigated. Successful completion of this subsystem test leads directly into system performance test. Here all APU components are assembled into a close-coupled test system. Sufficient component spacing is provided to permit access to instrumentation and components for repair or replacement. Performance will be measured with both sea-level and altitude exhaust pressures (fig. 9). The full power envelope will be explored while varying the propellant supply and working fluid temperature throughout their ranges. Finally, a 100-hour endurance test will be completed to demonstrate a durability level. A series of startups, shutdowns and output power changes typical of shuttle mission power profiles will be completed during the endurance test. All tests should be completed by October 1974. A major objective in the conduct of the test program is to produce data for validating the computer program to permit its use for scaling of power levels, operation of different mission profiles, and further investigation of transient and steady-state component characteristics. The total program effort including test data analysis and revision of the digital computer program for APU performance calculation will be completed in December 1974.

Closing Remarks

The revised APU configuration is an improvement over the initial reference unit with recycled flow. There is adequate capacity for cooling well beyond the specified amount. The combustor, a component whose performance gave us concern, has been tested successfully at steady-state conditions. Our periodic analysis of APU system weights continues to show a significant advantage in favor the H_2-O_2 APU. Technology and experimental results from this effort should provide the base necessary for a low-risk development program, leading to consideration of replacement of the current baselined N_2H_4 APU in the space shuttle with a H_2-O_2 APU.

References

1. Beremand, D. G.; Joyce, J. P.; and Cameron, H. M.: An H_2-O_2 Auxiliary Power Unit for Space Shuttle. IECEC Paper No. 729069, September, 1972.

2. Bailey, D. A.; and Burriss, W. L.: Hydrogen-Oxygen APU Control System Design. Prepared for presentation at the 8th IECEC, August 13-17, 1973.

3. Zuk, J.; Ludwig, L. P.; and Johnson, R. L.: High-Speed, Self-Acting, Face-Contact Shaft Seal. NASA Tech Brief No. B72-10114, Lewis Research Center, Cleveland, Ohio.

4. Gray, H. R.: Hydrogen Environment Embrittlement. NASA TM X-68088, June 26, 1972.

5. Harris, J. A.; and VanWanderham, M. C.: Properties of Materials in High Pressure Hydrogen at Room and Elevated Temperatures. PWA FR-5129, June 30, 1972. Annual report NASA Contract NAS8-26191.

Table 1

H_2-O_2 APU Specifications

Contract NAS3-15708

Power: 25-400 HP (Gearbox Shaft)

Hydrogen: 55^oR-560^oR (Liquid or Supercritical)

600 psi (Delivered)

Oxygen: 275^oR-560^oR (Supercritical)

900 psi (Delivered)

Response: Idle to peak in 0.075 sec.

Heat Rejection: Hydrogen provides 35 Btu/sec hydraulic & 20 Btu/sec lube cooling

Life: 1000 hours
900 hot starts
600 cold starts

TABLE 2

SHUTTLE APU SYSTEM WEIGHT COMPARISON

(4 APU'S; 200 HP-HR; 150 HP PEAK EACH APU)

ITEM	HYDRAZINE (PUMPED)	H_2-O_2 (PUMPED)*	H_2-O_2 (SUPERCRITICAL)
TURBINE POWER SYSTEM	1055	1195	1095
TANKS + SUPPORTS	285	590**	1145**
FLUIDS			
PROPELLANT(S)	1345	570	570
H_2O COOLANT + BOILER	900	0	0
TOTALS	3585	2355	2810
DELTA TOTALS		-1230	-775

*SUPERCRITICAL OXYGEN TANKAGE (150 LBS)

**AVERAGE BETWEEN AIRESEARCH & LERC CALCULATION

E-7553

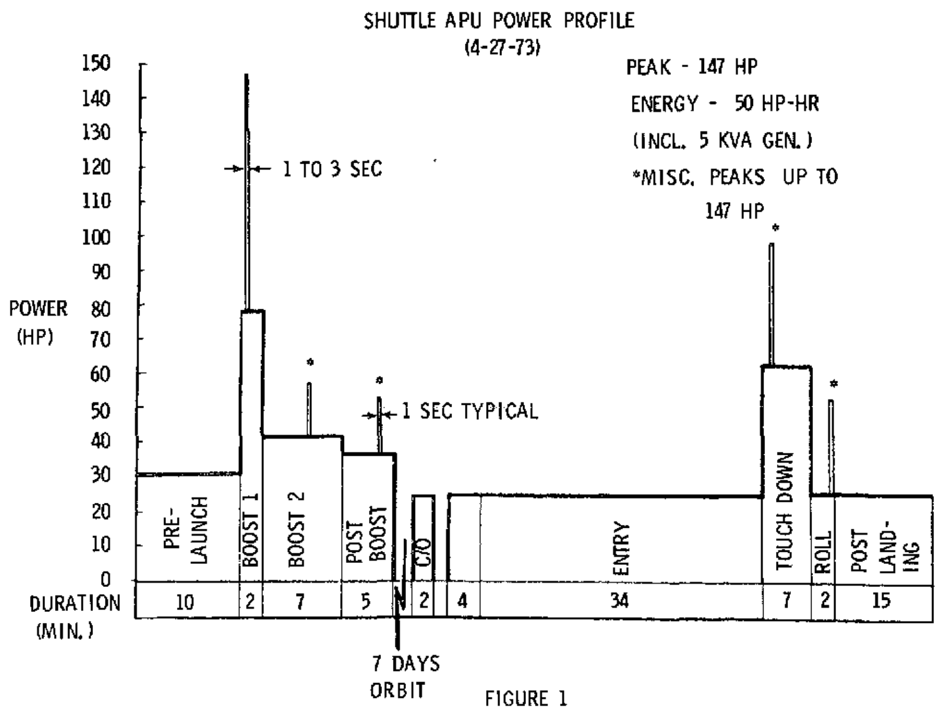


FIGURE 1

H_2-O_2 APU

SYSTEM SCHEMATIC

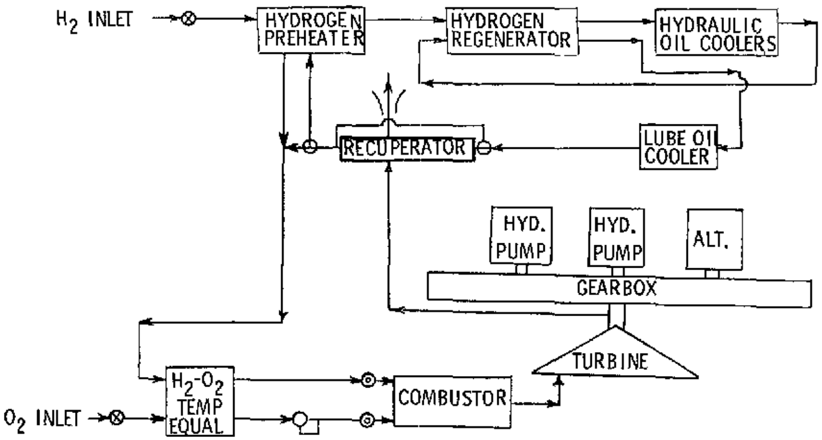
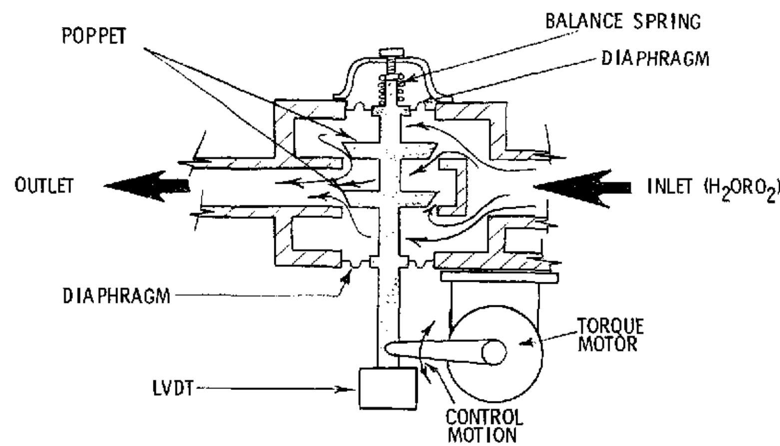


FIGURE 2

H_2-O_2 APU

FLOW CONTROL VALVE



BALANCED POPPET DESIGN - NO DYNAMIC SEALS

FIGURE 3

H_2-O_2 APU

SPECIFIC PROPELLANT CONSUMPTION

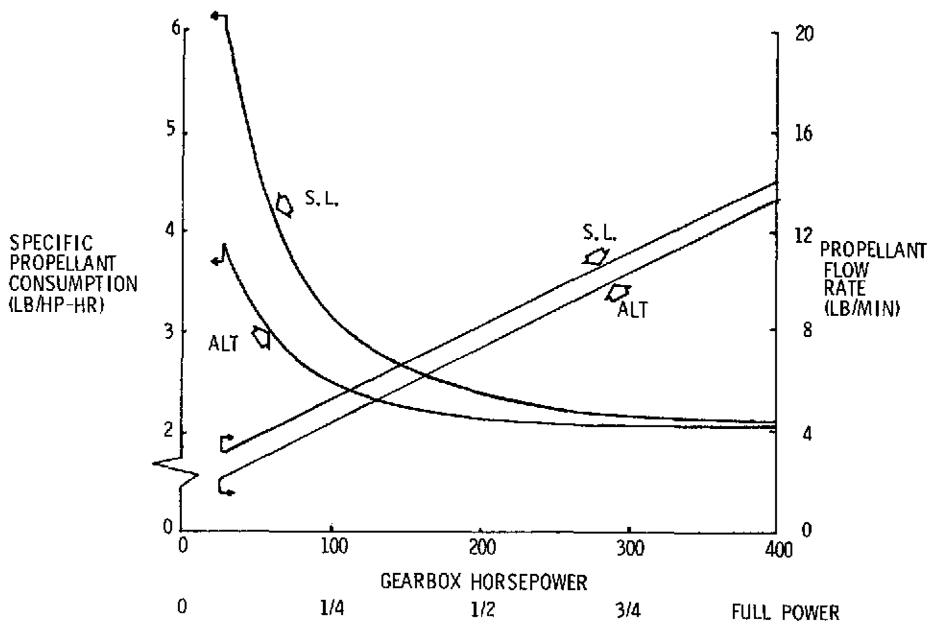
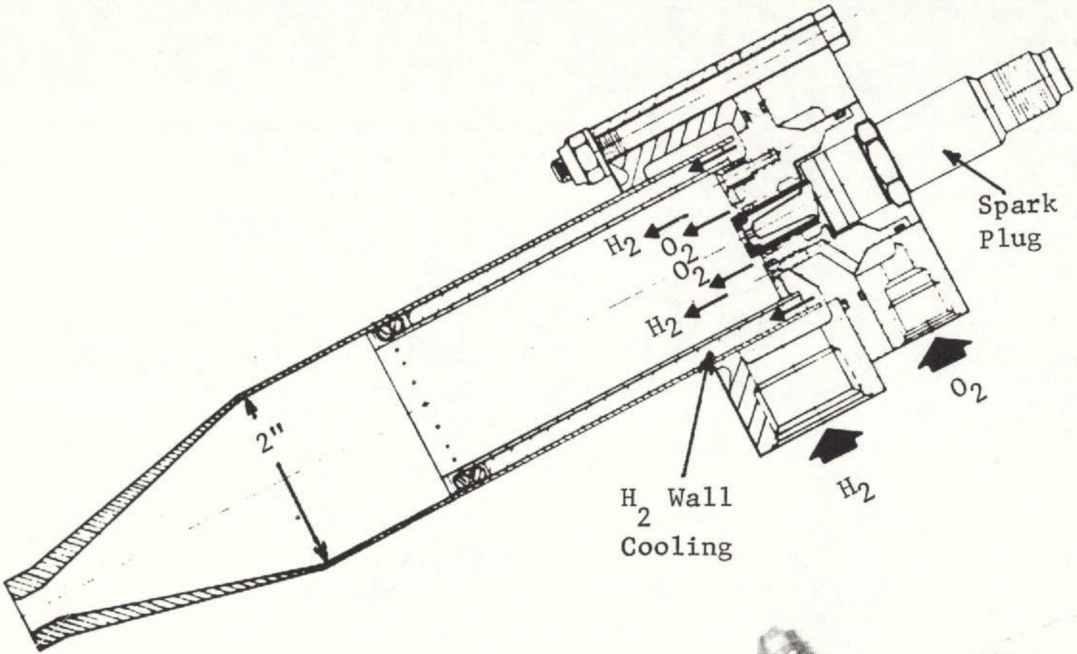
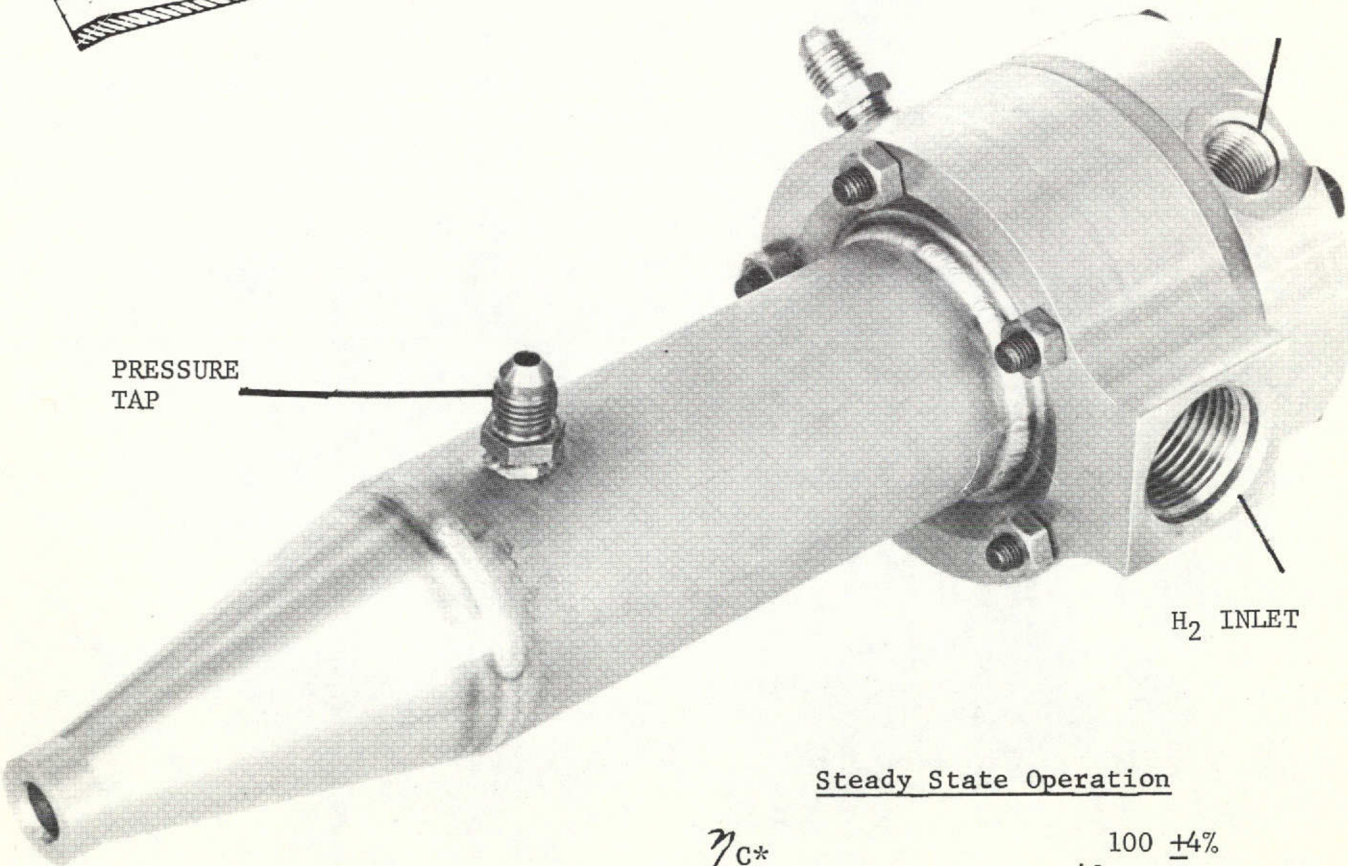


FIGURE 4

E-7553





Steady State Operation

η_{C*}	100 $\pm$4%
Runs	40
Chamber Pressure	35 to 431 psia
Temp. Profile	$\pm 160^{o}$
Injector ΔP	Design Value

Figure 5. H_2-O_2 APU Combustor

SPACE SHUTTLE H_2 – O_2 TURBINE 450 SHP

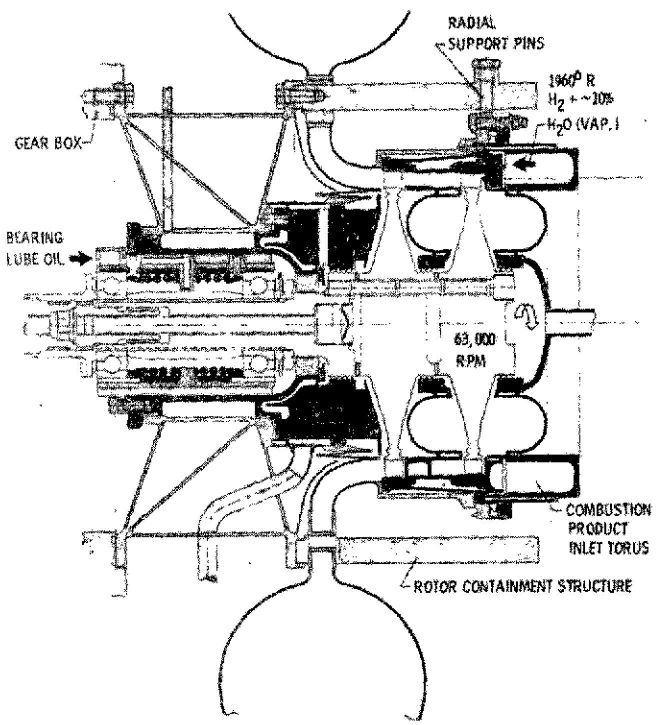


Figure 6.

H_2-O_2 APU COOLING CAPACITY

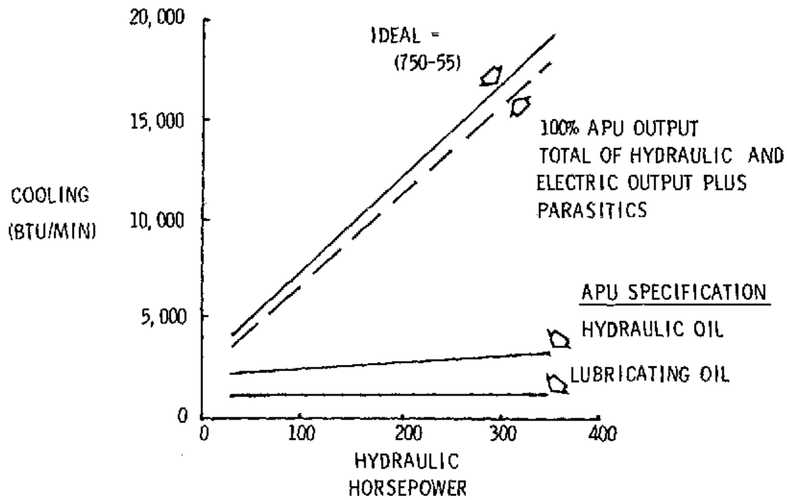


FIGURE 7

SHUTTLE APU UP-RATING

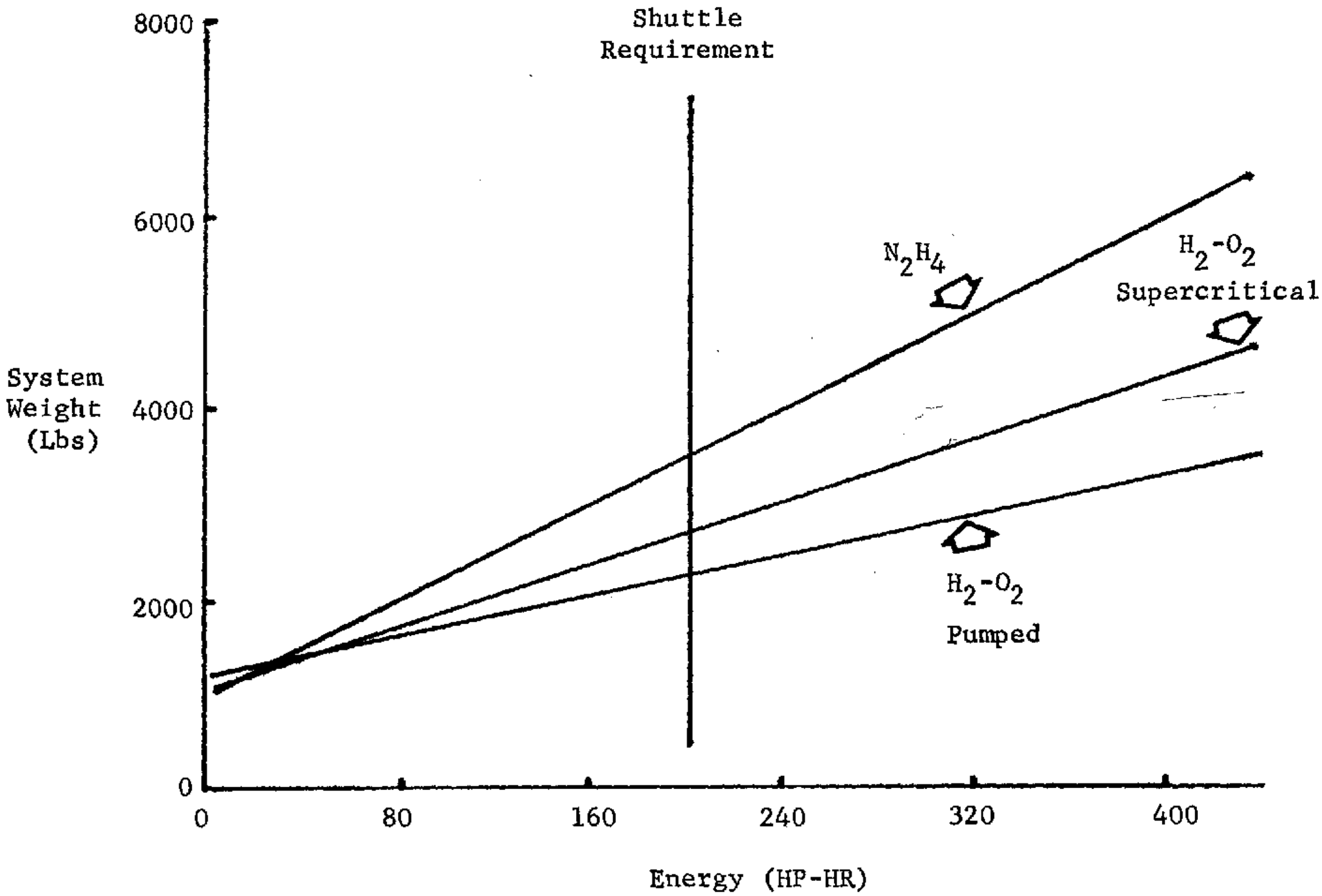


Figure 8

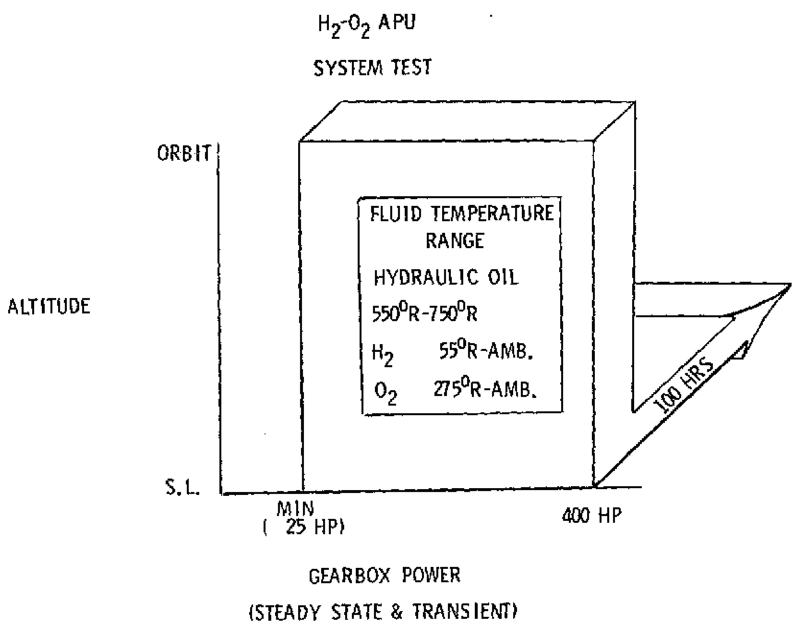


FIGURE 9

NASA-Lewis

E-7553